perspective. Previously, physics was the science of things as they are; astrophysics deals with the development of stars and galaxies, with the formation of the elements, with the expanding universe. There are many unsolved questions in this history, many phenomena, such as quasars, which are unexplained, but part of the history is fairly well understood. It is the part in which stars are formed from a hydrogen cloud, elements are formed by synthesis from hydrogen, and stars are developing through different states, some ending as cold chunks of solid matter, others ending in tremendous explosions which we observe as supernovas, sometimes leaving behind fast-spinning neutron stars.

One of these explosions occurred in the year A.D. 1054 and left behind the famous Crab Nebula, in which we see the expanding remnants of the explosion with a pulsar in the center. This explosion must have been a very conspicuous phenomenon, in its first days surpassing the planet Venus in brightness. So different from today's attitudes was the mental attitude in Europe at that time that nobody found this phenomenon worth recording. No records whatsoever are found in contemporary European chronicles, whereas the Chinese have left us meticulous quantitative descriptions of the apparition and its steady decline. What a telling demonstration of the tremendous change in European thinking that took place in the Renaissance!

The kinetic energies produced when large stars contract after their nuclear fuel is exhausted are such that individual protons reach energies of the order of several hundred million electron volts, not far from the energy of their rest mass. Therefore high-energy physics will come into play at these stages of development, and all the newly discovered phenomena of nucleon excitation and meson production will take place on a large scale, just as nuclear reactions take place on a large scale in the center of ordinary stars. Perhaps it is significant that such energies are reached when the gravitational energy of a particle becomes of the order of its mass. This is the so-called Schwartzschild limit, at which the gravitational field becomes critically large and the local space is heavily distorted. This may point to a connection between high-energy physics and gravitational phenomena.

The cosmological aspects of matter reveal a certain insignificance of electronic quantum physics in the universe. Only rarely is matter in a state where the quantum properties of electrons around nuclei are of relevance; for the most part, matter is too hot or too dilute. But it is at those special spots where quantum orbits can be formed that nature developed its atoms, its aggregates, its macromolecules, and its living objects. It is there that the greatest adventure of the universe takes place—that nature in the form of man begins to understand itself.

Employment Status of Recent Recipients of the Doctorate

Doctoral graduates in science and engineering have found professional employment despite a tightening job market.

Office of Scientific Personnel, National Research Council

In articles (*1*) and letters (*2*) published in scientific and professional journals, fears that Ph.D.'s may be in oversupply have recently been expressed. The authors of these articles and letters report that recipients of doctoral degrees are finding it increasingly difficult to obtain professional employment and that some are unemployed. "Is this country now producing more scientists than it can place in suitable scientific jobs?" asks one reporter (*3*). Echoes of these worries have reached a wider audience through newspapers (*4*) and magazines (*5*). Concern has not been limited to the employment prospects for new Ph.D.'s, but it has been especially acute in regard to this younger group.

Evidence cited for supposed unemployment of recipients of the doctorate is largely anecdotal and circumstantial rather than comprehensive and direct. Academic departments in some disciplines report that recent doctoral graduates have not been able to obtain suitable employment. The examples are scattered, however, and the number of authenticated cases of lasting unemployment is small. Dissertation advisers write letters to many colleagues, rather than to a few as in earlier years, in an effort to place their doctoral students in satisfying jobs. Graduate students, who had expected to be besieged by prospective employers, feel compelled to write large numbers of letters of application for jobs. Small academic departments that, a few years ago, were delighted to hear from a single well-qualified applicant for a faculty position now say they can choose from among many applicants from good universities. The ratio of employers to job seekers in the hiring halls of professional societies and college placement offices has shifted from 2 or 3 to fractional values during the last 2 years. Recruitment advertising by employers has diminished. All these developments indicate a tightening job market for Ph.D.'s, but they are not in themselves firm evidence of actual unemployment.

Reports and rumors of unemployment among Ph.D.'s have been accompanied, however, by changes in both demand and supply that have lent them credence. Actual and threatened reductions in federal support of research in universities have diminished research opportunities and have limited the growth of many departments on the larger campuses (*6*). The rate of increase of un-

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dergraduate enrollments is diminishing because of demographic trends that will continue well into the 1970's, and the need for new teachers is lessened (*7*). Cutbacks in major national programs, such as those in the space program, have led to reductions or closing of federal centers employing large numbers of doctoral scientists and engineers and have also affected their employment in related industry. Industrial laboratories seem, for the most part, to be following conservative personnel policies and engaging in limited and very selective recruitment. On the supply side, the output of new Ph.D.'s continues to grow, increasing by about 12 percent per year, as a consequence of the nation's expansion of graduate education earlier in this decade (*8*). The annual rate of increase is not uniform for all fields, however, ranging from a low of 1 percent in chemistry to a high of 18 percent in the biological sciences.

Although there is ample cause for concern, more substantial evidence about how recipients of the doctorate are adjusting to these new circumstances is required before credence is given to rumors of widespread unemployment. What is the status of employment of recent Ph.D.'s? This article contains information drawn from two national surveys conducted by the National Research Council with the cooperation of academic department chairmen, deans of graduate schools, and the doctorate recipients themselves. The fields covered are primarily the natural and social sciences, engineering, and mathematics, although some information concerning the humanities is also included. Recipients of earned research doctorates in the academic years 1967–68 and 1968–69 were included in the surveys.

A Departmental Survey of Doctoral Employment

Questionnaires were mailed on 26 December 1969 to the 4406 chairmen of academic doctoral departments of natural and social sciences, engineering, and mathematics, requesting their assistance in determining the employment status, as of the date of their reply, of recipients of doctoral degrees from these departments in the academic years 1967–68 and 1968–69. Not all of these departments have doctoral graduates each year. The principal employment categories investigated were as follows.

1) Temporary postdoctoral appointments (fellowships, traineeships, research associateships).

2) Foreign nationals who have left the United States.

3) Military service.

4) U.S. civilian positions which generally utilize the professional competence gained in graduate school.

5) U.S. civilian positions irrelevant to the individual's disciplinary competence.

6) Unemployed and presumably seeking employment.

7) Status unknown.

"Relevant" employment—category 4—was defined as follows: "positions which generally utilize the professional competence gained in graduate school. Included, for example, would be a faculty appointment in any university, college or junior college, a research position in industry or government, research administration in any organization, or any post of differing character if this was the result of a deliberate decision by the graduate rather than acceptance by default for lack of a more suitable opportunity." "Irrelevant" employment—category 5—was defined as a "position in which the graduate uses little or none of his scientific understanding or research competence and which he has accepted for lack of an opportunity more suitable in view of his training." Department chairmen were

Table 1. Numbers and percentages of recipients of the doctorate, by employment category and by size of institution, for all fields surveyed ("size" refers to total doctoral output for all doctoral fields combined). The values in parentheses in columns 1–7 are percentages computed on the basis of the total response reported in column 8. The values in parentheses in column 8 are percentages of the values in column 9 (see text).

Year of graduation	1 Temporary postdoctoral (*N*)	2 Foreign nationals who left the U.S. (*N*)	3 Military service (*N*)	4 Employment suitable (*N*)	5 Employment irrelevant (*N*)	6 Unemployed (*N*)	7 Status unknown (*N*)	8 Total response (*N*)	9 Total in survey fields (*N*)
				U.S. grand total					
1968	1328 (11.0)	859 (7.1)	267 (2.2)	9083 (75.1)	52 (0.4)	81 (0.7)	426 (3.5)	12,096 (78.4)	15,434
1969	2434 (17.7)	866 (6.3)	335 (2.4)	9405 (68.7)	91 (0.7)	157 (1.1)	403 (2.9)	13,691 (79.5)	17,219
				10 largest institutions					
1968	288 (10.4)	225 (8.1)	52 (1.9)	2018 (72.9)	5 (0.2)	25 (0.9)	157 (5.7)	2,770 (71.8)	3,856
1969	520 (17.0)	210 (6.9)	65 (2.1)	2049 (66.9)	11 (0.4)	35 (1.1)	172 (5.6)	3,062 (75.3)	4,069
				15 next-largest institutions					
1968	320 (12.3)	168 (6.5)	36 (1.4)	1897 (73.2)	10 (0.4)	20 (0.8)	142 (5.5)	2,593 (75.4)	3,437
1969	582 (19.6)	199 (6.7)	66 (2.2)	1981 (66.7)	14 (0.5)	43 (1.4)	87 (2.9)	2,972 (75.6)	3,933
				45 next-largest institutions					
1968	409 (10.6)	287 (7.4)	97 (2.5)	2956 (76.4)	16 (0.4)	22 (0.6)	82 (2.1)	3,869 (79.9)	4,842
1969	714 (16.6)	302 (7.0)	122 (2.8)	2998 (70.0)	46 (1.1)	38 (0.9)	78 (1.8)	4,298 (79.1)	5,437
				Remaining institutions					
1968	316 (11.0)	179 (6.3)	82 (2.9)	2212 (77.2)	21 (0.7)	14 (0.5)	45 (1.6)	2,864 (86.8)	3,299
1969	618 (18.4)	155 (4.6)	82 (2.4)	2377 (70.8)	20 (0.6)	41 (1.2)	66 (2.0)	3,359 (88.9)	3,780

Table 2. Numbers and percentages of recipients of the doctorate, by employment category and by field, for all U.S. institutions. The values in parentheses in columns 1–7 are percentages of the totals given in column 8. The values in parentheses in column 8 are percentages of the values in column 9.

Field	No. of depts.	1 Temporary postdoctoral (*N*)		2 Foreign nationals who left the U.S. (*N*)		3 Military service (*N*)		4 Employment suitable (*N*)		5 Employment irrelevant (*N*)		6 Unemployed (*N*)		7 Status unknown (*N*)		8 Total number reported upon		9 Total in survey fields (*N*)	
		1968	1969	1968	1969	1968	1969	1968	1969	1968	1969	1968	1969	1968	1969	1968	1969	1968	1969
Mathematics	150	14 (1.7)	43 (4.3)	47 (5.7)	44 (4.4)	18 (2.2)	20 (2.0)	725 (87.6)	854 (86.3)	3 (0.4)	1 (0.1)		7 (0.7)	21 (2.5)	20 (2.0)	825 (85.4)	989 (93.0)	970	1063
Physics	158	280 (22.9)	371 (28.1)	51 (4.2)	51 (3.9)	28 (2.3)	21 (1.6)	837 (68.3)	829 (62.8)	6 (0.5)	11 (0.8)	8 (0.7)	13 (1.0)	15 (1.2)	24 (1.8)	1225 (86.0)	1320 (90.9)	1424	1452
Chemistry	153	255 (16.4)	491 (28.4)	48 (3.1)	44 (2.5)	41 (2.6)	52 (3.0)	1136 (72.9)	1069 (61.8)	14 (0.9)	26 (1.5)	15 (1.0)	22 (1.3)	50 (3.2)	26 (1.5)	1559 (87.4)	1730 (88.9)	1784	1947
Earth Science	110	23 (5.6)	66 (13.8)	35 (8.5)	49 (10.3)	14 (3.4)	8 (1.7)	331 (80.3)	341 (71.5)	2 (0.5)	3 (0.6)		4 (0.8)	7 (1.7)	6 (1.3)	412 (93.8)	477 (95.0)	439	502
Engineering	456	51 (2.0)	152 (5.0)	165 (6.5)	177 (5.8)	74 (2.9)	119 (3.9)	2049 (80.5)	2346 (77.5)	3 (0.1)	13 (0.4)	9 (0.4)	53 (1.8)	193 (7.6)	166 (5.5)	2544 (89.7)	3026 (93.6)	2836	3234
Subtotals	1027	623 (9.5)	1123 (14.9)	346 (5.3)	365 (4.8)	175 (2.7)	220 (2.9)	5078 (77.3)	5439 (72.1)	28 (0.4)	54 (0.7)	32 (0.5)	99 (1.3)	286 (4.4)	242 (3.2)	6568 (88.1)	7542 (92.0)	7453	8198
Biochemistry	106	172 (42.7)	289 (59.3)	31 (7.7)	32 (6.6)	9 (2.2)	9 (1.8)	179 (44.4)	144 (29.6)	1 (0.2)	6 (1.2)	6 (1.5)	3 (0.6)	5 (1.2)	4 (0.8)	403 (70.2)	487 (89.0)	574	547
Agricultural sciences	148	23 (3.7)	56 (8.6)	176 (28.3)	148 (22.7)	14 (2.3)	21 (3.2)	401 (64.6)	398 (60.9)	1 (0.2)	5 (0.8)		8 (1.2)	6 (1.0)	17 (2.6)	621 (91.7)	653 (80.1)	677	815
Health sciences	169	48 (15.4)	107 (30.3)	24 (7.7)	30 (8.5)	8 (2.6)	8 (2.3)	224 (72.0)	197 (55.8)	2 (0.6)	1 (0.3)	1 (0.3)	2 (0.6)	4 (1.3)	8 (2.3)	311 (78.5)	353 (81.0)	396	436
Other biological sciences	510	378 (19.5)	716 (34.0)	153 (7.9)	141 (6.7)	37 (1.9)	33 (1.6)	1316 (67.8)	1158 (55.0)	10 (0.5)	18 (0.9)	25 (1.3)	23 (1.1)	21 (1.1)	17 (0.8)	1940 (95.3)	2106 (90.9)	2036	2318
Subtotal	933	621 (19.0)	1168 (32.5)	384 (11.7)	351 (9.8)	68 (2.1)	71 (2.0)	2120 (64.7)	1897 (52.7)	14 (0.4)	30 (0.8)	32 (1.0)	36 (1.0)	36 (1.1)	46 (1.3)	3275 (88.9)	3599 (87.4)	3683	4116
Psychology	96	62 (6.8)	112 (10.4)	12 (1.3)	28 (2.6)	21 (2.3)	18 (1.7)	747 (81.5)	844 (78.4)	1 (0.1)		12 (1.3)	12 (1.1)	62 (6.8)	62 (5.8)	917 (63.0)	1076 (62.3)	1456	1728
Other social sciences	274	22 (1.6)	31 (2.1)	117 (8.8)	122 (8.3)	3 (0.2)	26 (1.8)	1138 (85.2)	1225 (83.1)	9 (0.7)	7 (0.5)	5 (0.4)	10 (0.7)	42 (3.1)	53 (3.6)	1336 (47.0)	1474 (46.4)	2842	3177
Grand total	2330	1328 (11.0)	2434 (17.7)	859 (7.1)	866 (6.3)	267 (2.2)	335 (2.4)	9083 (75.1)	9405 (68.7)	52 (0.4)	91 (0.7)	81 (0.7)	157 (1.1)	426 (3.5)	403 (2.9)	12096 (78.4)	13691 (79.5)	15434	17219

invited to add comments to their statistical reports.

In all, 2330 department heads replied by 10 February 1970. Collectively, their departments had granted 25,787 doctorates—78.6 percent of the Ph.D.'s granted in their fields—during the 2-year period in question. Although there was a slight amount of double-counting (of people who were claimed by more than one department), this represented probably no more than a few percentage points in any major field and was undoubtedly balanced by underreporting from other departments. Because the pattern of results, in major outline, is very similar across all fields, institution sizes, and geographic regions, we believe that little distortion of results was induced by any nonrepresentativeness of the respondents. Responses were, quite understandably, received earliest and in greatest abundance from the smaller departments, since the status of graduates was better known to the department heads in these instances. The larger departments, however, were well represented.

Table 1 gives the number of recipients of the doctorate by employment category and by size of institution, where "size" refers to total doctoral output for all doctoral fields combined. Columns 1 through 7 in Table 1 correspond to the seven employment categories listed above. The percentages given in these columns (the values in parentheses) are computed on the basis of the total response reported in column 8. The percentages in column 8 are computed on the basis of the total number (column 9) of Ph.D. degrees granted by the institutions included in each size grouping in the fields surveyed.

Table 2 gives the number of recipients of the doctorate in 1968 (that is, academic year 1967–68) and in 1969 (academic year 1968–69) by employment category and by field of specialization, for all U.S. institutions. Again, columns 1 through 7 correspond to the seven employment categories. Figure 1 presents these data graphically for the 1969 recipients only.

The popularity of postdoctoral appointments varies greatly from field to field, as shown in Fig. 1. Care should be exercised, however, in interpreting the increases in postdoctoral appointments from 1968 to 1969 (Table 2). There are several quite different factors involved in this upward shift. One is an artifact: the 1968 graduates on 1-year postdoctoral appointments have

completed them and are now in regular employment. This is shown (Table 2, column 4) by an overall increase in the percentage in positions utilizing the professional competence gained in graduate school: 75.1 percent for the 1968 graduates as against 68.7 percent for the 1969 graduates. The second factor is the historical trend for an increasing percentage of new Ph.D.'s in the fields surveyed to seek immediate postdoctoral experience [the reasons for this have recently been explored in considerable detail (*9*)]. The third factor, occasionally alluded to in voluntary comments by the department chairmen, is that, to some extent, temporary postdoctoral positions have of late been used for stopgap employment of a department's own graduates who have not found immediate employment elsewhere. To the extent that this has occurred (and this cannot be determined from the statistics of Table 2), the nature of these appointments has shifted from the original intent of providing further training in research.

Foreign nationals who returned to their home countries account for 7.1 percent of the 1968 graduates and 6.3 percent of the 1969 graduates (Table 2, column 2). This is less than half the percentage of all foreign citizens who received earned doctorates in the United States in these 2 years. In the fields surveyed, foreign nationals have in recent years comprised over 15 percent of all Ph.D.'s, and in certain fields, such as engineering and agriculture, they have comprised from one-fourth to one-third of all Ph.D.'s. Evidently, most foreign nationals are not leaving the country on attaining the doctorate but are remaining and seeking employment here. Many comments by the department chairmen indicate that it is the foreign nationals who are having the greatest difficulty in finding employment. The year-to-year change in the percentage of those who return to their home countries suggests that some return after a year or so spent in trying unsuccessfully to find jobs in the United States. The greatest numbers of unassimilated foreign citizens are from India and Taiwan, to judge from the comments that accompanied the returned questionnaires.

Military service claimed 2.2 percent of the 1968 graduates and 2.4 percent of the 1969 graduates, and these percentages do not vary markedly by field or by size of institution. Some undetermined number of these individuals are officers sent to graduate school by the military departments for the express purpose of obtaining training needed in their military jobs.

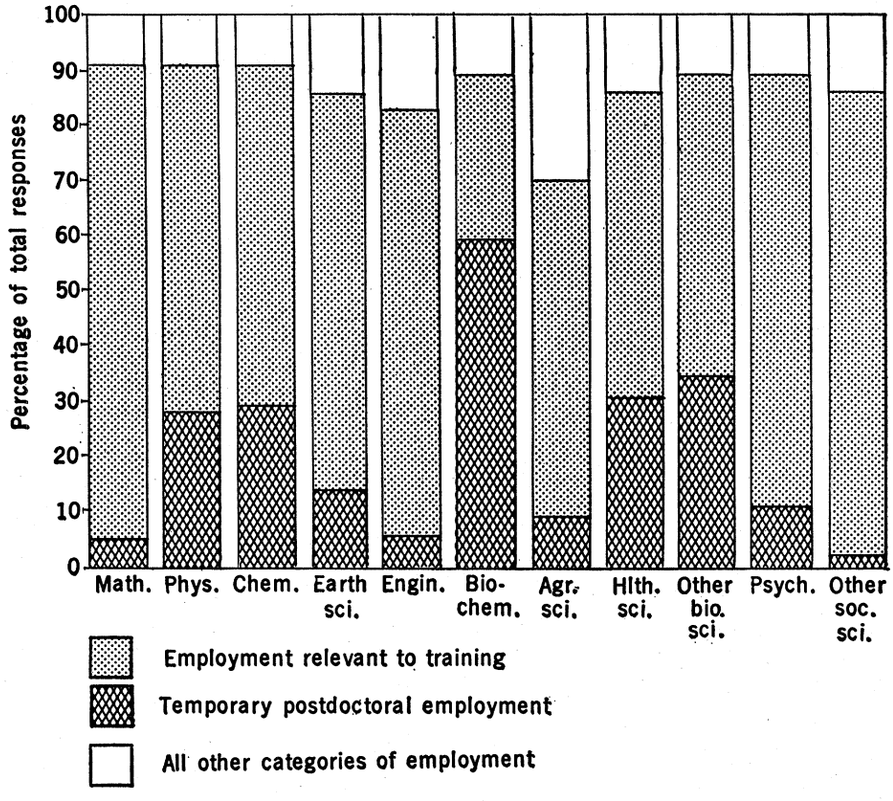

Fig. 1. Percentages of recipients of the doctorate in 1969 who are in postdoctoral appointments, in employment relevant to their training, and in all other employment categories (categories 2, 3, and 5–7, as given in text), by field of specialization.

Most of the graduates in both years and in all fields except biochemistry (where over half hold postdoctoral appointments) are employed in U.S. civilian positions that utilize their professional competence. Overall, this category included 75.1 percent of the 1968 graduates and 68.7 percent of the 1969 graduates. In all fields this percentage is lower for 1969, but usually by an amount that approximately balances the increase in the percentage of individuals reported holding postdoctoral appointments.

Those in positions irrelevant to their training constitute less than 1 percent overall, in either year. Only in chemistry and in biochemistry does this percentage ever exceed 1 percent; in those fields it reaches 1.5 and 1.2 percent, respectively. In chemistry, the comments of department chairmen indicated that there was a simultaneous retrenchment in government programs, in industry, and in the academic community. Most of those who commented on this situation seemed to regard it as temporary.

In all fields the unemployed were somewhat more numerous than the irrelevantly employed, but only by a fraction of a percentage point. The figures on unemployment are slightly inflated by the inclusion of some people who were not seeking employment. Respondents to the questionnaire indicated in some cases that they had included housewives with young children and persons electing to travel. Altogether, such qualifying comments referred to about one-fifth of the unemployed. The comments also indicated, as noted above, that a disproportionate number of those who were unsuccessful in finding employment were foreign citizens, but no exact figures are available.

"Status unknown" accounted for 3.5 percent of the 1968 graduates and 2.9 percent of the 1969 graduates. This figure may be too low, because it varies according to the size of the institution reporting, and the larger institutions were somewhat less well represented in the questionnaire returns. It is, however, a remarkably low percentage for such a survey as this, in view of the difficulties department chairmen must encounter in keeping in touch with their graduates over a period of about 2 years.

Comments of the Department Chairmen

Many department chairmen added comments on the employment and recruitment situations. In field after field, they reported that their new Ph.D.'s all had jobs, but, comparing the flood of applications they themselves had received with the small number of jobs they had to offer, they thought the situation must be very tight. One further summarized the complex dynamics of this situation as follows: "At the convention, the book of 'positions wanted' was thicker than the book of 'positions available.' However, several, myself included, did not advertise in the 'available' book, to avoid being flooded by candidates. We had no problem placing our Ph.D.'s."

This situation seems particularly to characterize the field of physics. In that field fewer than 1 percent are reported as unemployed and even fewer are reported in employment irrelevant to their training. Yet all comments were to the effect that a flood of applications had been received in physics. By contrast, in chemistry, where the statistics indicated a situation no better than that in any other field of science, no overwhelming flood of applications was reported.

With the change from a distinctly "seller's" toward a "buyer's" market, departmental recruiters were able to relax their efforts, making the situation *seem* to change much more than it actually had changed. The students, sensing or being told about the decline, began to send out multiple applications where formerly they had waited for offers and had chosen the best of several. This altered the situation as perceived by recruiters, and a positive feedback situation developed, changing a mild decline into a panic. One recruiter who spent a considerable amount of time interviewing applicants also reported some inflation in the character of the recommendations as compared with former years, because, he felt, the recommenders were trying harder to "sell" their students.

The comments reported below were selected as being representative and as delineating changes within each of the major fields, since different fields were frequently affected differently by the general decline in the "seller's" market. In each field the comments have been selected to show the range from optimistic to pessimistic attitudes and to present nuances and color that will put more meaning into the bare statistics.

In mathematics the situation is best summarized by one department chairman, who said, "The number of bright, promising researchers . . . now clearly exceeds the number of teaching positions in first-line research-oriented universities. However, many good colleges and most of our 2-year colleges have need for much better educated faculties in mathematics." Another said, "All do get jobs of the type they wish, but they must look aggressively for them." Another commented on the "financial crisis in higher education. . . . departments are shorthanded, but haven't the budget to hire as many people as they need," while a fourth spoke of "a downward shift of more competent people into the junior colleges and high schools; such a development is much to be desired." Statistics and computer science fields reported a very brisk "seller's" market, whereas the more "pure" fields reported a "buyer's" market.

In physics, comments were plentiful and indicated a widespread apprehension, coupled with a near-universal placement of 1968 and 1969 graduates. Typical were the following: "During the past six months we have had 121 inquiries, 75 in theoretical-particle and high-energy physics . . . zero positions

Table 3. Percentages of doctorate recipients continuing with immediate postdoctoral study, by field of doctorate, by citizenship, and by year of receipt of doctorate.

Citizenship	Percentage in immediate postdoctoral study, by year of receipt of doctorate											
	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
						Mathematics						
U.S.	5.9	4.9	8.2	7.0	12.0	8.0	6.8	5.7	5.7	5.9	3.8	6.1
Non-U.S.	2.9	2.3	1.7	8.2	8.9	7.0	3.9	9.1	6.5	10.7	7.4	14.4
Total	5.5	4.5	6.9	7.2	11.3	7.9	6.3	6.3	5.9	6.7	4.4	7.4
						Physics						
U.S.	5.7	6.0	9.4	12.2	17.2	16.1	17.5	17.2	23.7	23.2	18.4	31.9
Non-U.S.	10.5	6.0	9.9	20.8	15.4	20.1	13.2	20.6	16.7	23.3	23.3	44.5
Total	6.2	6.0	9.4	13.6	16.9	16.8	16.7	17.8	22.3	23.2	19.3	34.0
						Chemistry						
U.S.	5.8	11.4	14.6	21.2	24.0	25.7	26.9	27.8	26.3	28.1	27.7	32.1
Non-U.S.	12.4	12.2	22.6	32.0	30.9	29.3	25.9	27.8	27.9	34.2	35.6	37.9
Total	6.5	11.5	15.5	22.8	24.9	26.2	26.7	27.8	26.6	29.1	28.8	32.9
						Earth science						
U.S.	3.2	0.5	5.3	7.7	8.6	7.9	6.7	8.9	12.9	10.6	8.1	17.6
Non-U.S.		4.8	2.1	13.5	3.6	7.4	3.4	8.6	12.9	14.0	14.1	20.2
Total	2.6	1.3	4.7	8.5	8.0	7.8	6.1	8.8	12.9	11.3	9.4	18.2
						Engineering						
U.S.	1.0	1.3	3.1	2.6	3.3	5.6	5.0	5.6	4.7	3.7	3.4	4.7
Non-U.S.	4.7	4.0	4.3	4.2	5.6	4.8	6.9	5.0	6.1	6.4	7.2	10.7
Total	1.7	2.0	3.4	3.0	3.9	5.4	5.5	5.5	5.0	4.4	4.6	6.2
						Biological sciences						
U.S.	6.9	10.9	15.9	21.3	22.4	22.5	23.1	25.9	25.7	27.6	29.6	33.3
Non-U.S.	4.8	9.2	10.8	17.3	17.6	18.3	17.1	19.4	18.4	23.1	24.5	31.4
Total	6.6	10.6	15.0	20.5	21.5	21.7	21.7	24.3	24.1	26.6	28.5	32.9
						Social sciences						
U.S.	1.7	3.8	4.9	5.6	5.9	6.0	5.8	7.2	7.0	7.0	6.4	7.4
Non-U.S.	2.0	2.1	2.8	2.1	3.9	3.5	3.2	3.4	3.9	3.8	4.2	7.5
Total	1.8	3.7	4.6	5.2	5.6	5.7	5.4	6.6	6.5	6.5	6.0	7.4
						Total, science and engineering fields						
U.S.	4.4	6.9	9.9	12.6	14.0	14.2	14.1	15.2	15.5	15.8	15.3	18.7
Non-U.S.	5.2	6.4	8.4	13.7	12.5	12.9	11.7	13.2	12.7	15.4	15.7	21.7
Total	4.5	6.8	9.6	12.7	13.8	14.0	13.7	14.9	14.9	15.7	15.4	19.3

available." "We anticipate some problem in placing our weaker graduates beginning perhaps next year, but up to now it has been very easy." "I believe that the situation is worse than my figures indicate. Our one unemployed Ph.D. is a foreign national who should really return to his home country . . . about half of our [1970] Ph.D.'s have not yet found positions. . . ." Several commented on the discrepancy between the expectations of the new Ph.D.'s and the positions needing to be filled: "The one listed as unemployed is a girl who had a baby recently. A number of 4-year and 2-year colleges in this area do not have adequate teaching staff. The demand is *good* for Ph.D.'s—we need 2 to 3 junior men in this department." "There are plenty of jobs for people to teach physics, but how many new Ph.D.'s are willing to do such work?" ". . . well-qualified candidates do not have difficulty . . . only those who are poorly prepared or narrowly educated have severe problems."

In chemistry, typical comments were as follows: "Superb men . . . are not able to get academic positions with the certainty of the past . . . in university research." "Our Ph.D.'s gain employment—the problem is *where* and in *what capacity* . . . usually *not* where they first wish . . . though still definitely as chemists." "Academic jobs have declined seriously. Some Ph.D.-trained chemists may enter the junior college system. This would be a rather interesting development." In the geosciences, two comments suffice: "As far as the geosciences [geology, geochemistry, geophysics, hydrology] are concerned, employment has never been so good!" "No employment problem . . . but too high a percentage of Ph.D.'s want to teach in prestige institutions." In engineering the comments were much the same as in the geosciences, and this included all the various subfields. In biochemistry there were mixed responses, best summarized by the comment, "Employment is available but its nature is somewhat different—industrial employment and academic employment in smaller institutions."

The biological sciences present a mixed picture in which those fields related most closely to the practice of medicine are booming—typically, they report shortages from mild to severe—while other areas report some slackening of demand. Plant pathologists report some difficulty: "In plant pathology at the present there are more *good candidates* available than there are positions. The post-doc route is intrinsically of great value, but is being resorted to in many departments as a stopgap procedure." The situation in microbiology is quite the opposite: "I could have placed 20 to 30 Ph.D.'s into *academic* positions this year, not four, not counting the commercial vacancies." Veterinary medicine reports a brisk demand, as does the field of nutrition, while there is reportedly some softening of the market in forestry, horticulture, and agronomy. In agricultural economics the following comment appears representative: "Demand for the top 25% is *very* strong, but demand for the lower 25% is weak. With few vacancies in universities and U.S.D.A. [the U.S. Department of Agriculture], most of this year's group have gone into industry in economic research." In zoology, one chairman said, "Positions in zoology are 'tight' or 'loose' in part according to specialty. The recent reduction in the rate of increase in funds voted by state legislatures should soon be translated to a tightening of the open positions." Another commented, "There is a slackening demand for entomologists. However, we have not encountered any difficulty in placing our doctoral graduates. Our emphasis on a strong background in applied ecology is producing graduates for which there is continuing demand." This was echoed by another: "We have had no trouble placing our ecology graduates even though the selection has become more limited"; this indicates that the impact of a national concern with environmental quality may be very great on a numerically small field.

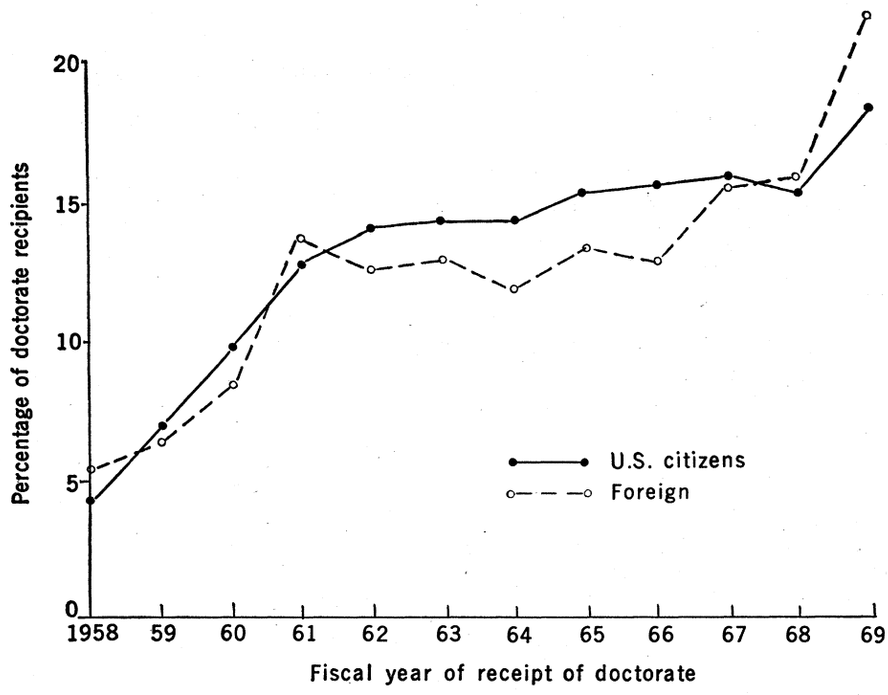

Fig. 2. Percentages of recipients of the doctorate in fiscal years 1958 through 1969, in the fields surveyed, who took a postdoctoral temporary appointment immediately upon graduation.

In all the medical sciences, shortages were reported. Numerous unfilled positions in anatomy were reported, including those needed, those authorized, and those actually funded. Personnel shortages were also reported in microbiology, physiology, and pharmacology and in the several clinical fields.

In the social sciences, as in the biological fields, the demand for Ph.D.'s varied from weak to very strong. One psychology department chairman, apparently typical, reported, "Jobs are tighter. They still usually have 2 to 4 choices, as compared with 5 to 8 a few years ago." In geography the demand is keen. A typical comment was, "A shortage of Ph.D.'s continues to exist in geography. The college and university teaching market may be saturated by the mid-70's, however." In sociology, a chairman reports, "The market seems to be changing. Our graduates are still being placed, and in good universities, but there are signs of a change. One receives many more letters of inquiry." Economics seems to be in a favorable position: "We had little trouble in placing our Ph.D.'s in university employ-

Table 4. Employment status at time of receipt of doctorate, by fiscal year in which doctorate was received (1964 or 1969), by field of doctorate, and by citizenship.

Citizenship	Signed contract (%)		Negotiating, specific employer (%)		Seeking, no prospects (%)	
	1964	1969	1964	1969	1964	1969
Physical sciences						
U.S.	84	81	10	9	6	10
Non-U.S.	72	63	11	14	16	22
Total	82	78	10	10	7	12
Engineering						
U.S.	84	81	13	12	4	6
Non-U.S.	71	65	16	16	12	19
Total	81	77	14	13	5	9
Biological sciences						
U.S.	83	78	11	11	6	11
Non-U.S.	74	65	12	12	13	23
Total	81	75	11	11	8	13
Social sciences						
U.S.	87	84	7	8	5	7
Non-U.S.	81	80	9	10	10	11
Total	86	84	7	8	6	7
Total, science and engineering fields						
U.S.	84	81	10	10	5	8
Non-U.S.	74	68	12	13	13	19
Total	83	79	10	10	7	10

ment or government research agencies. The one whose status is listed as unknown is independently wealthy and has not looked for a job as far as I know." A political science department chairman comments: "There is no question but what every Ph.D. could, at the moment, find teaching employment if he were willing to accept any job in the marketplace. But most of our Ph.D.'s aspire higher than the bottom third of higher educational institutions. So far, all have ultimately found this type of position." Anthropology departments report no severe difficulties, but two chairmen offer interesting comments: "Despite the shortage of men, women Ph.D.'s are not being hired at the rate they should be," and "Canadian universities are making attractive offers to anthropologists trained in the United States."

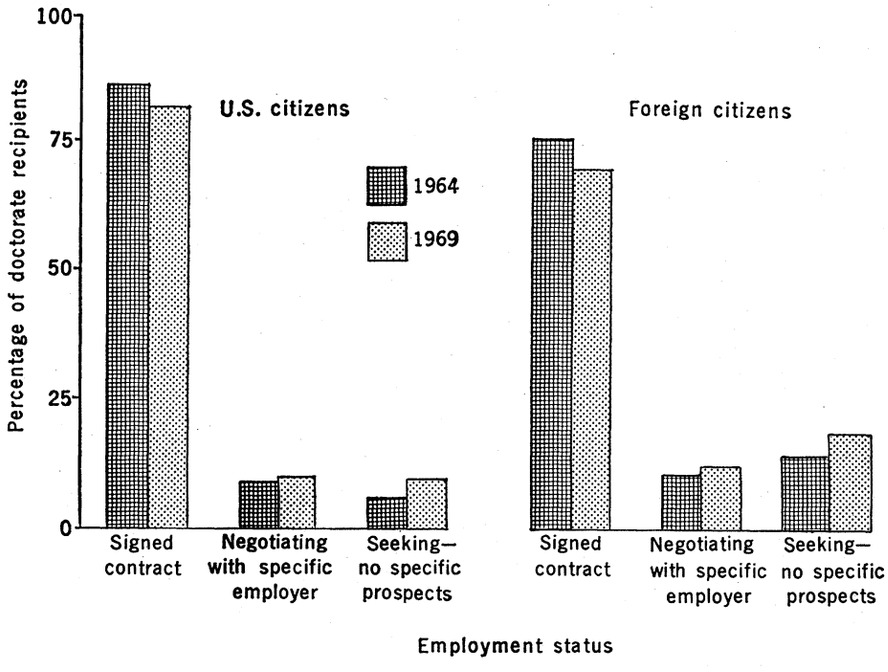

Fig. 3. Percentages of recipients of the doctorate in fiscal years 1964 (hatched columns) and 1969 (dotted columns), in the fields surveyed, by employment status at the time of graduation, for U.S. citizens (graph at left) and foreign citizens (graph at right). Recipients who took temporary postdoctoral appointments immediately upon graduation are excluded. [Doctorate Records File, Office of Scientific Personnel, National Research Council]

Employment Plans of Doctorate Recipients

The Doctorate Records File (DRF), a repository of information from the Survey of Earned Doctorates, contains information that throws further light on the initial postdoctoral employment status of recent recipients of the doctorate. Conducted annually by the Office of Scientific Personnel of the National Research Council, the Survey gathers information by means of a questionnaire form distributed with the cooperation of graduate deans and filled out by the graduates just as they complete all requirements for their doctoral degrees. The survey covers research doctorates in all fields, including the humanities, but professional degrees such as the M.D., D.D.S., and D.V.M. are not included. The accumulated records for all these individuals are called the Doctorate Records File and provide a virtually complete listing of all recipients of research doctorates since 1920. However, not all respondents answer every question—the typical response rate is about 95 to 98 percent. Information about postdoctoral employment status has been gathered since 1958.

Data from the Doctorate Records File provide a perspective of the employment status of doctorate recipients that differs somewhat from the perspective given by the statistics reported above. The DRF data represent the recipients' statements rather than those of the department chairmen; the File covers all fields and is not restricted to the sciences and engineering; and the DRF data can reveal trends over longer periods, and reveal detail by citizenship.

The Survey of Earned Doctorates seems to provide reliably predictive data on immediate employment of the graduating Ph.D.'s. For example, when a follow-up study of recipients who had graduated in 1965 was made from the 1966 National Register of Scientific and Technical Personnel, it was found that the information given by them in the Survey was still about 80 to 90 percent accurate. That is, of those listed in the National Register, over 90 percent were employed in the geographic area in which they had expected to be employed, 89 percent were employed by employers in the category they had expected, and 85 percent were principally engaged in work of the type they had anticipated prior to graduation. It is possible that the tightening job market has reduced the predictive value of these statements of intention by the doctoral

graduates, but we believe the collection of the data comes late enough in the job-seeking process to make them still of value.

The immediate postdoctoral professional activities of recipients of the doctorate are analyzed in the Doctorate Records File by two categories: (i) additional study in the form of postdoctoral fellowships, traineeships, or associateships, and (ii) permanent employment. Figure 2 and Table 3 show that the percentage of doctorate recipients in the natural and social sciences, engineering, and mathematics who went immediately into postdoctoral study increased rapidly from fiscal year (FY) 1958 to about FY 1963 and then leveled off until FY 1968. In FY 1969, however, the percentage abruptly increased. The pattern holds for both U.S. and non-U.S. citizens. This trend is most strikingly illustrated in the field of physics, in which the percentage of individuals entering postdoctoral study had leveled off at about 20 percent through FY 1968 and then rose to about 34 percent in FY 1969. One-fourth of the increment in the numbers of such individuals between FY 1968 and FY 1969 was in physics.

The most direct measure from the Doctorate Records File of the immediate employment status of doctorate recipients is the response to the following question:

How well defined are your postdoctoral plans?

- Have signed contract or made definite commitment.
- Am negotiating with a specific organization, or more than one.
- Am seeking, but have no specific prospects.
- Other (specify)

In Fig. 3 and Table 4 the responses to this question by the FY 1964 and the FY 1969 recipients of the doctorate are compared. The data also enable one to compare the responses of U.S. citizens with the responses of foreign nationals, and they show detail by field of doctorate. It should be remembered that these statistics represent the individual's employment status just prior to official receipt of the doctorate—a point about 6 to 9 months earlier then the time at which the departmental survey, reported above, was conducted. Also, these data describe only persons eligible for immediate employment, excluding those who indicated they had accepted temporary postdoctoral fellowships or traineeships. In general, the situation in 1969 was little different from that existing 5 years earlier. The percentage of those who had "signed [a] contract" had dropped slightly. The percentage of those still "seeking" had increased from 5 to about 10 percent, but "seeking" at the time of response should not be interpreted as "unemployed" at present. In most fields the percentage of those "seeking" is much higher among the non-U.S. citizens than among the U.S. citizens. The data indicate a tightening of the job market but give little evidence of appreciable unemployment among the Ph.D.'s.

Table 5. Type of first postdoctoral primary work activity, by fiscal year in which doctorate was received (1964 or 1969), by field of doctorate, and by citizenship.

Citizenship	Research and development (%)		Teaching (%)		Other* (%)	
	1964	1969	1964	1969	1964	1969
			Physical sciences			
U.S.	64	55	34	42	2	3
Non-U.S.	61	54	38	42	1	3
Total	63	55	35	43	2	2
			Engineering			
U.S.	58	68	39	29	3	5
Non-U.S.	69	62	30	33	1	4
Total	60	68	37	28	3	4
			Biological sciences			
U.S.	53	46	43	48	4	6
Non-U.S.	59	56	37	42	4	2
Total	54	47	42	47	4	4
			Social sciences			
U.S.	26	20	53	64	21	16
Non-U.S.	34	24	59	68	8	9
Total	27	21	54	64	20	15
			Total, science and engineering fields			
U.S.	47	39	43	52	10	9
Non-U.S.	52	44	44	51	4	4
Total	48	40	43	52	9	8

*Administration and professional services to individuals.

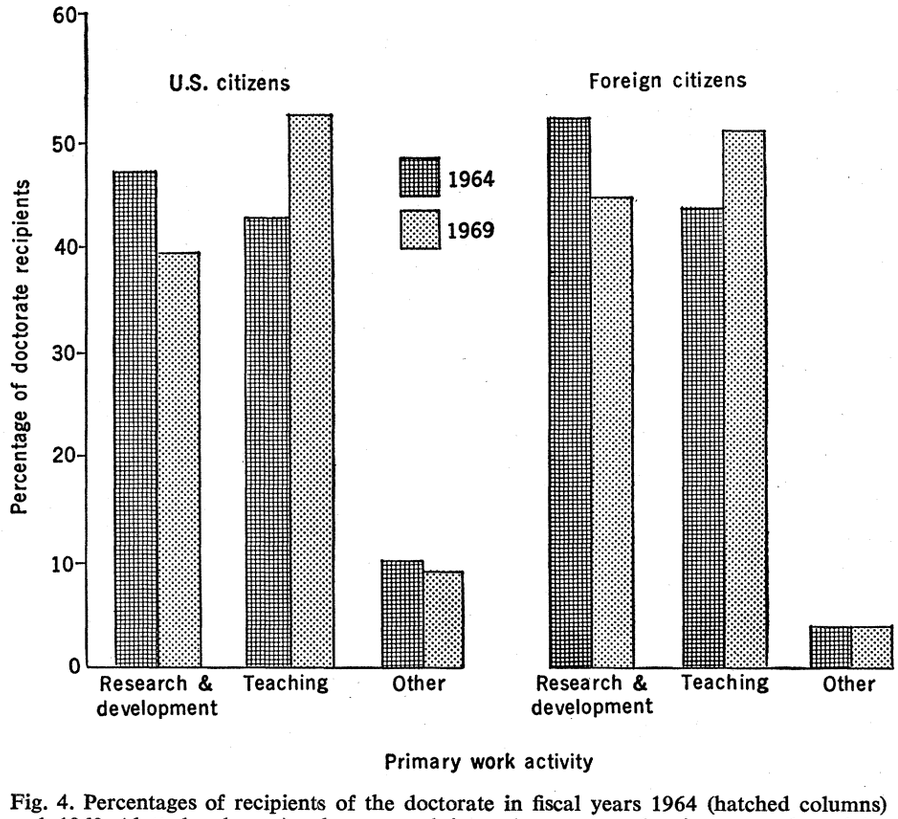

Fig. 4. Percentages of recipients of the doctorate in fiscal years 1964 (hatched columns) and 1969 (dotted columns) who engaged in various types of primary work activity (or, at the time of graduation, had contracts to do so), for U.S. citizens (graph at left) and foreign citizens (graph at right). Recipients who took temporary postdoctoral appointments immediately upon graduation are excluded.

The FY 1969 recipients of the doctorate in the fields considered here differ significantly from the FY 1964 group in the type of postdoctoral primary work activity they report. Figure 4 and Table 5 show that much larger percentages of those in the physical sciences, biological sciences, and social sciences reported teaching as their primary work activity in FY 1969 than in FY 1964. The data show a corresponding drop in the percentage of those reporting research and development as primary activities in FY 1969. For engineers, however, this pattern was reversed—a larger percentage of the FY 1969 group than of the FY 1964 group reported research, and a smaller percentage reported teaching, as their primary work activity. The other fields reported very small percentages in research in both FY 1964 and FY 1969. The data describe those who were eligible for employment (excluding those who had accepted postdoctoral study appointments) and who indicated they had signed a contract.

The decrease in research and the corresponding increase in teaching may indicate changing interests of recipients of the doctorate, or—more probably—may indicate the acceptance of second-choice positions.

In the FY 1969 questionnaire the recipient of the doctorate was also asked to report the field of specialty in which he was working if he had secured employment by the time of his response. Ninety percent of those responding reported that their field of employment was the same as that of their doctoral major; this indicates that the great majority of those who were employed were utilizing their graduate training.

A Note on Recipients of the Doctorate in Other Fields

The preceding sections have dealt with the employment status of recent recipients of the doctorate only in the natural and social sciences, mathematics, and engineering. The Doctorate Records File also contains information about recipients of research doctorates in the arts and humanities, education, and certain other professional fields (law, business administration, religion and theology), which collectively account for 35 percent of the total number of doctorates annually awarded in recent years.

Only a small fraction of the recipients in these three broadly grouped areas take an immediate temporary postdoctoral appointment (fellowship). Between 1958 and 1968, the percentage remained under 2 percent. In 1969, 2 percent of the recipients of doctorates in the arts and humanities, 1.1 percent of those in education, and 2.5 percent of those in the other professional fields named above took an immediate postdoctoral appointment. Over 90 percent of the 1969 recipients of the doctorate in the arts and humanities and 82 percent of those in the professional fields reported that teaching would be their primary work activity after they had received the degree. In education, 52 percent planned to teach, 10 percent planned to engage in research and development, and 40 percent expected to be involved in other activties, such as administration. These percentages do not differ markedly from percentages based on the reports of the doctorate recipients of 5 years earlier. The employment status of the FY 1964 and FY 1969 recipients of the doctorate in these fields at the time the degree was received is shown in Table 6.

Table 6. Employment status at time of receipt of doctorate, by fiscal year in which doctorate was received (1964 or 1969), by citizenship, and by field of doctorate, in the arts and humanities, in education, and in certain other professional fields.

Citizenship	Signed contract (%)		Negotiating, specific employer (%)		Seeking, no prospects (%)	
	1964	1969	1964	1969	1964	1969
			Arts and humanities			
U.S.	88	86	6	5	4	8
Non-U.S.	86	77	6	7	6	15
Total	88	85	6	5	5	9
			Education			
U.S.	87	80	7	9	6	11
Non-U.S.	73	76	13	8	14	15
Total	86	80	7	9	7	11
			Other professional fields			
U.S.	90	87	6	8	4	5
Non-U.S.	81	84	10	10	9	6
Total	89	86	6	8	5	5

Summary

The evidence from two national surveys indicates that virtually all recipients of the doctorate in the sciences and in engineering during the last 2 academic years have found employment in a constricted job market. For the most part they have found professional employment relevant to their training. The movement of Ph.D.'s into teaching positions in increasing numbers may prove to be a major benefit to this country in the days ahead, whatever temporary disappointments such career decisions hold for some of those who made them. The evidence does not support the notion that widespread unemployment or maldistribution of training and talents exists among recent doctoral graduates.

Investment by the public and private sectors in the education of doctoral graduates, including investment by the Ph.D.'s themselves, is so great that no degree of continuing unemployment can be regarded with complacency. The distress of individuals at finding their training and talents unused is real, whatever the gross statistics may say. If unemployment extends beyond what is normal for a mobile population at a time of career transition, invaluable human resources are being wasted, and the problem rises to a level of national urgency.

Forestalling such a situation or dealing with it if it arises requires objective and comprehensive examination of the problem, with recognition of the differences among the disciplines in regard to the balance of supply and demand. This article is a contribution to such an examination, and there should be others. The National Research Council intends to repeat the departmental survey of doctoral employment in a year, and to extend it to examination of the subsequent employment of those who now hold temporary postdoctoral appointments (*10*). This article was written at the time of year when, normally, most emerging Ph.D.'s seek and find employment. Apprehension that appropriate positions will be even less available than they were last year is running high. It is hoped, however, that the difficulties facing doctoral graduates and causing some of them

to despair may again be mitigated by a job market that, in the outcome, proves to be sufficiently large, even if it is one of changing character.

Disappointment and unmet expectations are a more subtle, but an equally real, problem. They exist on both sides—in some, perhaps many, doctoral recipients who have accepted jobs which utilize their advanced education but which are quite different from those they anticipated, and in employers who find in some new Ph.D.'s narrowness of view and lack of motivation for work outside their specialized research interests. Solution of this complex problem will require examination of the graduate education process, the informal counseling between professors and graduate students, the expectations of employers, and the values that universities and the larger society attach to graduate education and academic scholarship. National organizations can play a useful role in stimulating a search for solutions that must, in the end, be developed for many different local situations.

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Cryobiology: The Freezing of Biological Systems

The responses of living cells to ice formation are of theoretical interest and practical concern.

Peter Mazur

Freezing is lethal to most living systems; yet it can also preserve cells and their constituents, and it may some day permit the long-term storage of whole viable organs. It can slow or stop some biochemical reactions, but it accelerates others. It is used both to preserve the fine structure of cells and to disrupt cells. It is a challenge that is successfully met by some organisms in nature but not by others.

These paradoxes illustrate some of the divergent areas in biology in which low temperatures are of interest; other examples are listed in Table 1. But although the reasons for the interest are diverse and even paradoxical, all the areas are concerned with the ways in which biological systems respond to subzero temperatures and to the solidification of liquid water. My purpose in this article is to discuss some general conclusions that can be drawn about these responses, some of the major questions that remain unresolved, and the way in which some of the various areas of cryobiological interest relate to one another.

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Events during Freezing

Although the freezing point of cytoplasm is usually above −1°C (corresponding to osmolal concentrations below 0.5), cells generally remain unfrozen, and therefore supercooled, to −10° or −15°C, even when ice is present in the external medium (*1*). This indicates that the cell membrane can prevent the growth of external ice into the supercooled interior, and it further indicates that cells neither are, nor contain, effective nucleators of supercooled water. I return to these points toward the end of the article.

Since intracellular freezing is precluded above about −10°C and since supercooled water has a higher vapor pressure than ice, cells begin to equilibrate by losing water. The resulting dehydration concentrates their solutes, thus lowering the intracellular aqueous vapor pressure. Subsequent events during cooling depend chiefly on the cooling velocity and on the permeability of the cell to water (*2*). If cytoplasm obeyed Raoult's law and if water did *not* flow out of the cell, the ratio of intracellular to extracellular vapor pressure (p_i/p_e) would increase with decreasing temperature (T, in degrees Kelvin) according to the relation

$$\frac{d \ln (p_i/p_e)}{dT} = \frac{nv}{(V + nv)V} \frac{dV}{dT} - \frac{L_f}{RT^2} \quad (1)$$

where n is the number of osmoles of solute in the cell, v is the molar volume of water, V is the volume of water in the cell, L_f is the heat of fusion, and R is the gas constant.

But water will flow out of the cell in response to the vapor pressure gradient; and, if one assumes that the cell is permeable only to water, the rate of outflow will be

$$-\frac{dV}{dt} = \frac{L_p ART}{v} \ln (p_i/p_e) \quad (2)$$

where t is the time, L_p is the permeability constant for water, and A is the area of the cell surface. If the cooling rate and temperature dependence of L_p are known, one can obtain simultaneous numerical solutions to Eqs. 1 and 2 to give the volume of water in a cell as a function of temperature, cooling rate, and permeability to water. Examples of such numerical solutions are